Nucleic Acids: DNA and RNA

Nucleic Acids
Responsible for the transfer of genetic information.

Two forms of nucleic acids:
- Ribonucleic Acid (RNA)
  - Mainly found in cytoplasm
- Deoxyribonucleic Acid (DNA)
  - Found in the cell nucleus (eukaryotic)

Nucleic Acids, cont.
- Nucleic acids are polynucleotides, or polymers composed of many repeating units of nucleotides.
- Each nucleotide consists of a nucleoside coupled together with a phosphate group.
- Each nucleoside is made up of a nitrogen base unit derived from either purine or pyrimidine ring bonded to either a ribose or deoxyribose sugar unit

Building Blocks of Nucleic acids

- Nucleic acid
- Nucleotide
- Nucleoside
- Phosphate

- Nitrogen base-pyrimidines or purines
- Sugar unit Ribose or 2-deoxyribose

Building Nucleic acids

- Sugar unit Ribose or 2-deoxyribose + Nitrogen base-pyrimidines or purines = Nucleoside + Phosphate = Nucleotide + Nucleotide + ... = Nucleic acid

Sugar Units

Beta hydroxyls are the site of the nitrogen base ester linkage

- RNA sugar unit: β-D-Ribose
- DNA sugar unit: β-D-2-Deoxyribose
Nucleoside Bases
Two purine bases and three pyrimidine bases are found in the nucleotides present in nucleic acids.

Numbering Carbons
• Since the carbons of the nitrogen base rings are also numbered according to the IUPAC system. Therefore, the conventional way to name nucleosides is to number the base carbons as 1,2,3... and the carbons of the sugar units as 1',2',3',...

Nucleotide formation
• The nitrogen base attaches by an amide linkage to the hydroxyl of the anomeric carbon on the sugar ring (named carbon 1').
• The phosphate is bonded by an ether linkage to the carbon above the plane on the sugar ring (carbon 5').

Primary Structure of Nucleic Acids
• Nucleosides are linked together by phosphates in phosphodiester linkages forming polynucleotides, or nucleic acids.

Primary Structure of Nucleic Acids, cont.
• Notice, the phosphate of one nucleotide attaches to the 3' carbon of the sugar unit of the next nucleotide.
• Also, the Base units act as functional groups off of the phosphate sugar backbone.
Comparison between a nucleic acid molecule and a protein

Notice the end designations for the nucleic acid:

- **5’ end** referring to the hydroxyl on the 5\(^{th}\) carbon of the sugar ring
- **3’ end** referring to the hydroxyl on the 3\(^{rd}\) carbon of the sugar ring

![Diagram of nucleic acid and protein structures]

DNA vs. RNA

- Since all the sugar units of this nucleic acid are β-D-2-deoxyribose units, this is a DNA molecule
  - RNA is composed of only β-D-ribose sugar units.

DNA vs. RNA, cont.

- DNA is built on a backbone of phosphate and β-D-2-deoxyribose units with attached Adenine (A), Thymine (T), Guanine (G), and Cytosine (C) nitrogen base units on the 1’ carbon, or A, T, G, and C nucleotide units.
  - DNA molecules can range from 1-100 million nucleotide units.

DNA vs. RNA, cont.

- RNA backbone of phosphate and β-D-ribose units with attached Adenine (A), Uracil (U), Guanine (G), and Cytosine (C) nitrogen base units on the 1’ carbon, or A, U, G, and C nucleotide units.
  - Notice, Uracil replaces Thymine in RNA
  - RNA molecules range from as few as 73-thousand nucleotide units.
  - RNA and DNA have very different secondary structures.

Shorthand Notation

- The primary structure of DNA and RNA is described by the sequence of nucleotides linked together forming the phosphate/sugar backbone.
  - Since each strand of DNA or RNA is so long, scientists use shorthand to describe the sequence of their bases.
  - By convention, we start at the 5’ end:
    - Example: 5’ U-A-G-U-G-C-C…, 3’
    - (Is this DNA or RNA? How can you tell?)
Secondary Structure of DNA

Double-helix secondary structure of DNA

• Deduced by Watson and Crick (1953).
• Two antiparallel strands wound in a helix.
• Held together by the specific matching of apposing base pairs by hydrogen bonding called complementary base pairing.

The “Founders” of the DNA double Helix

J.D. Watson (left) and F.H.C. Crick (right), working with their model of the DNA double helix.

Secondary Structure of DNA

• AT pair consist of 2 H-bonds (human DNA consist of 30% each)
• GC pair consist of 3 H-bonds (human DNA consist of 20% each)

Prokaryotic cell DNA

• found in bacteria.
• genomes of prokaryotes are contained in single chromosomes, which are usually circular DNA molecules.

Eukaryotic Cell DNA

• Found in plants, animals, Fungi and protists.
• Genomes of eukaryotes are composed of multiple chromosomes, each containing a complex linear molecule of DNA. Although the numbers and sizes of chromosomes vary considerably between different species their basic structure is the same in all eukaryotes.

Tertiary Structure of DNA

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Tertiary Structure cont.

The DNA of eukaryotic cells is tightly bound to small basic proteins (histones) that package the DNA in an orderly way in the cell nucleus. This task is substantial, given the DNA content of most eukaryotes. For example, the total extended length of DNA in a human cell is nearly 2 m, but this DNA must fit into a nucleus with a diameter of only 5 to 10 µm.
The extent of chromatin condensation varies during the life cycle of the cell. We will only discuss the life cycle of somatic (body) cells as they undergo mitosis and will leave zygotes (sex cells), which undergo meiosis, for AP biology.

During the majority of a cell's life span, or interphase, most of the chromatin is relatively decondensed and distributed throughout the nucleus as unwound nucleosomes. In this period of the cell cycle, DNA is replicated in preparation for cell division and genes are transcribed for protein synthesis.

During the first phase of mitosis, prophase, the nucleosomes condense into fibers that are in-turn condensed onto special proteins called scaffold proteins. The 30-nm chromatin fibers fold upon themselves with the help of scaffold proteins condensing DNA nearly 10,000-fold. The newly condensed strands of DNA begin to bind to identical strands formed during replication.

During metaphase, anaphase and telophase the two sister chromatids are separated and nuclear membranes re-form around the separated chromatids as they de-condense back to chromatin, resulting in two daughter cells each containing a nucleus with a copy of the parental DNA strand.

Chromosomes are formed from one condensed chromatin strand binding to an identical strand replicated during interphase. The two identical bound strands, or sister chromatids, are held together at a condensed region called the centromere by interactions of specialized regions on each sister chromatid strand with proteins.
Secondary structure of RNA

- Unlike DNA, RNA is a single strand of nucleotides (with the exception of some viruses). Because of this, RNA does not need complimentary pairs for each nucleotide.
- RNA molecules contain regions of double-helical structure where they form loops.

Ebola virus

Secondary structure of RNA, Cont.

- In the regions of hydrogen bonding, helical structure exists.
- The subsequent folding of the RNA molecule gives rise to its secondary structure.
- RNA lacks any real tertiary structure.

RNA in the Cell

- Unlike DNA, RNA is distributed throughout cells. It is present in the cytoplasm, mitochondria and nucleus.
- Each type of RNA performs an important function in protein synthesis and cellular processes.

RNA from a human cell

Three types of RNA

- Messenger RNA (mRNA) – carries genetic information from DNA in the nucleus to ribosomes, site of protein synthesis, in the cytoplasm.
- Ribosomal RNA (rRNA) – main component of ribosomes (65%) that are the site of protein synthesis. The rRNA maintains the structure of the ribosome and provides sites for the binding of mRNA.
- Transfer RNA (tRNA) – delivers individual amino acids to the site of protein synthesis.